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DESIGNING FOR BANK EROSION CONTROL WITH VEGETATION,(U)
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(14) CERC-REPRINT-78-2

(6) DESIGNING FOR BANK EROSION CONTROL WITH VEGETATION,

by

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(11) Feb 78
(12) 19p.

ABSTRACT

Marsh plants are effective in stabilizing eroding banks in sheltered coastal areas. Exceptional results have been achieved in a variety of intertidal environments at a fraction of the cost required for comparable structural protection. Techniques are available for the efficient propagation of several marsh plants for use in bank stabilization. This paper provides design criteria for (1) determining site suitability, (2) selecting plant materials and planting methods and (3) estimating labor requirements on a project by project basis.

INTRODUCTION

Bank erosion is a common problem in the bays, sounds and estuaries of the coastal United States. A wide variety of structures have been developed and used to control erosion in these areas. However, due to environmental objections and cost limitations it is often impractical to use even the most innovative of these structures. This is particularly true for low wave energy areas where erosion may be costly but is not yet castostrophic. Low cost, non-structural techniques are now available for controlling erosion in these areas using native marsh plants.

BACKGROUND

In the late 1960's the Coastal Engineering Research Center initiated research on the use of marsh plants for bank erosion control. In field trials exceptional results were achieved in a variety of intertidal environments at a fraction of the cost required for comparable structural protection. For example, in the spring of 1974 a rapidly eroding shoreline in Bogue Sound, North Carolina was planted with a native marsh grass (Figure 1). The operation including digging, processing and mechanical planting required less than 15 man-hours/100 linear feet (30 meters) of shoreline. By the end of the second growing season (Figure 2) the planted area was effectively stabilized (Woodhouse, Seneca and Broome, 1976).

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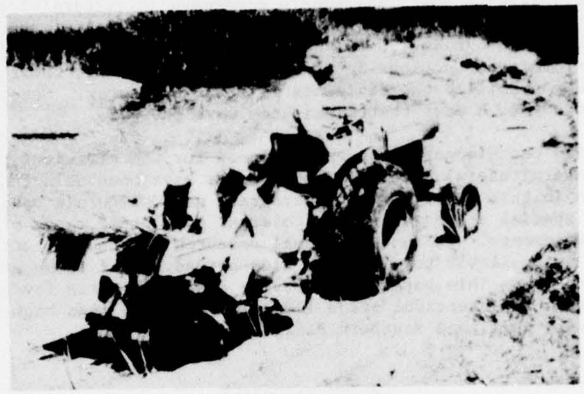

FIGURE 1. Pine Knoll Shores, Bogue Sound, North Carolina; May 1974.

FIGURE 2. Pine Knoll Shores, Bogue Sound, North Carolina; September 1975.

Studies have identified several marsh plants that are effective stabilizers. Major research emphasis has focused upon several representatives of the genus Spartina; smooth cordgrass (*S. alterniflora*), saltmeadow cordgrass (*S. patens*), gulf coast cordgrass (*S. spartinae*) and California cordgrass (*S. foliosa*). Studies have indicated that plants perform two functions in abating erosion. First, their extensive root systems stabilize the sediments in which they grow. Second, their aerial parts form a mass that dissipates wave energy.

Detailed techniques have been developed for the efficient propagation of several useful species. Two species have been selected for discussion in this paper: smooth cordgrass and California cordgrass. These two species are particularly tolerant to a broad range of intertidal environments. Though additional research is needed, sufficient knowledge is available to allow the wide-spread use of these grasses to control erosion. This paper will provide design criteria for planting these grasses in intertidal areas (mean low water to mean high water) on the Atlantic, gulf, and southern Pacific coasts.

PLANT MATERIALS

Smooth cordgrass occurs along the Atlantic and gulf coasts from southwest Texas to Newfoundland (Mobberley, 1956 and Correll, 1972). California cordgrass occurs intermittently along the California coast and the coast of Baja California, Mexico (Munz, 1968 and Mason, 1969). For the most part these two species are geographically separated on the North American continent. Neither species is found along the northern Pacific coast or in the Great Lakes region.

Both grasses are very similar in appearance (Figure 3 and 4). Each is a perennial grass which spreads by means of subsurface rhizomes (horizontal branching rootstock). Smooth cordgrass ranges in height from 2 to 8 feet (0.6 to 2.5 meters) and California cordgrass is shorter, ranging from 1 to 4 feet (0.3 to 1.2 meters). Their seedheads (inflorescences) are long and narrow, 0.3 to 1.3 feet (0.1 to 0.4 meters) in length for smooth cordgrass and 0.3 to 0.8 feet (0.1 to 0.25 meters) in length for California cordgrass. Similarities between the two species extend beyond appearances; both plants respond to similar propagation techniques.

PLANTING METHODS

Seeding.

Both smooth cordgrass and California cordgrass may be propagated by seed. Seeds are ready for harvesting as early as September in northern latitudes and as late as November in southern areas. Seed-producing stands should be examined periodically during appropriate months. When seeds are easily dislodged by grasping the seed head, harvesting should begin. To harvest, clip seed head from adult plant. After harvesting, store collected material two weeks in a moist condition, thresh and store in cold (39° Fahrenheit, 4° Celsius), brackish water (Woodhouse, Seneca, and Broome, 1974 and Knutson, 1976). Broadcast at low water

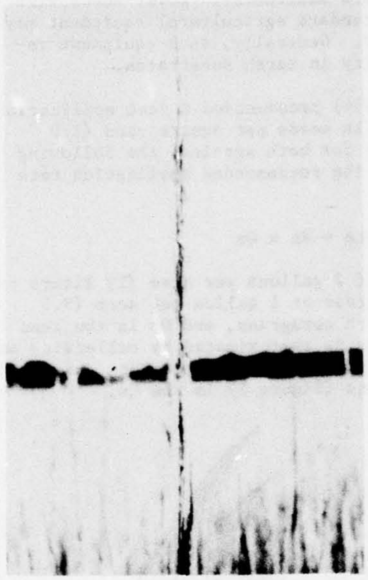

FIGURE 3. Smooth cordgrass
Chesapeake Bay, MD

FIGURE 4. California cordgrass
San Francisco Bay, CA

during late winter or spring (February through April in southern latitudes and March through May in northern latitudes). Cover seeds with one-half inch or less of tillage. Standard agricultural equipment may be used to harvest and broadcast seed. Generally, such equipment requires modification to achieve mobility in marsh substrates.

Woodhouse, Seneca, and Broome (1974) recommended a seed application rate for smooth cordgrass of 100 viable seeds per square yard (1.0 square meter). Using this as a guide for both species, the following volumetric equation was formulated. The recommended application rate for seed is given by:

$$\text{Seed application rate} = Ra \times Qs$$

where Ra is a base application rate of 2 gallons per acre (19 liters per hectare) of seed for California cordgrass or 1 gallon per acre (9.5 liters per hectare) of seeds for smooth cordgrass, and Qs is the seed quality index for the seed source. Qs is approximated by collecting and examining seed before harvest. The total number of spikelets examined divided by the number of full spikelets (Figure 5) is the Qs. Threshing will reduce the volume of harvested material by about 50 percent. Therefore, the volume which must be harvested in anticipation of planting is:

$$\text{Harvest volume} = 2(Ra \times Qs) \times A$$

Where A is the area to be planted in acres.

FIGURE 5. Full Spikelet

Planting Sprigs.

A sprigging technique can be used to plant both species. A sprig is a part of a plant consisting of at least one node (joint of a stem from which the leaves arise) with attached stems and roots. To obtain sprigs, dig plants from existing marshes or "nurseries" established for this purpose and separate them. (CAUTION--this activity is potentially damaging to existing, natural marshes. Avoid disruption of areas subject to erosion.) Obtaining and separating sprigs is much more efficient in sandy substrates and in young stands where dense root systems have not yet formed. Sprigs must be kept moist until planting and may be heeled-in for several days in an intertidal area. (Do not allow plants to overheat by covering or keeping in closed containers.) To plant, open a hole 4 to 6 inches (10 to 15 centimeters) in depth, insert the sprig, and firm the soil. Early spring is optimal for planting, although moderate success can be obtained in other seasons. A modified tobacco planter may be used to increase planting efficiency on sandy sediments. Sprigs should be planted on 24-inch centers (46 centimeters) or 18-inch centers (61 cen-

timeters) in areas of critical erosion. Spacing at 18 and 24 inches requires 19,400 and 10,900 plants per acre, respectively. (Woodhouse, Seneca, and Broome, 1976).

Planting Plugs.
Plugs may be used to plant California cordgrass, but have not been tested for smooth cordgrass. A plug is a root-soil mass, 4 to 6 inches (10 to 15 centimeters) in diameter and 6 to 8 inches (15 to 20 centimeters) deep which contains roots and a number of stems. Plugs can be excavated from existing marshes and transplanted intact. Collect plugs in cohesive sediments only; and intact root-soil sediment mass cannot be maintained in sandy sediments. Plugs may be planted during any season (except in areas with ice formation) though spring is preferable. Caution against disrupting natural marshes also applies here. Plugs should be planted on 24-inch centers, 10,900 per acre (Knutson, 1975 and Knutson, 1976).

Planting Nursery Seedlings.
Smooth cordgrass and California cordgrass may be planted using nursery seedlings rooted in peat moss pots. Seedlings have a well-developed, intact root-soil mass for planting in either cohesive or sandy sediments. Seedlings have several advantages. Nursery stock can be (a) held indefinitely in the event of construction delays, (b) planted in most any season, though spring is preferred and (c) cultivated with a minimum of disturbance to existing marshes. To prepare nursery seedlings, collect and store seed as discussed above. Seeds may be stored up to 8 months. Remove seeds from storage and scatter over the surface of 3- to 5-inch (8- to 13- centimeters) diameter peat moss pots filled with sand. Apply approximately 10 seeds per pot, scarify lightly, irrigate with tapwater and apply 10-10-10 fertilizer at 0.25 ounce per square foot (315 grams per square meter) after seeds have germinated (Dr. E. W. Garbisch, President, Environmental Concern Inc., personal communication, 1977).

Seedlings should be grown for at least 3 months before planting. Maintain salinity in the solution comparable to that which will be encountered at the planting site. Planting of both plugs and seedlings is more efficient if holes are opened with an auger. Seedlings should be planted on 24-inch centers, 10,900 per acre (Garbisch, 1975).

Fertilization Requirements.
Fertilization is recommended for all bank stabilization projects. For seeded areas, apply to the surface two parts (by weight) ammonium sulfate or ammonium nitrate to one part treble-superphosphate. Fertilize with 200 pounds per acre (220 kilograms per hectare) in June and in July of the first growing season (a total of 400 pounds).

For areas planted with sprigs, plugs and seedlings, apply to the surface two parts (by weight) ammonium sulfate or ammonium nitrate to one part treble-superphosphate. Fertilize with 200 pounds per acre (220 kilograms per hectare) at time of planting and in June (a total of 400 pounds) or side dress (1 ounce per plant) with 8- to 9-month release fertilizer at time of planting. Application rate per unit area for side dressing is dependent upon spacing requirements (18- and 24-inch spacing

requires 1,200 and 700 pounds per acre or 1344 and 784 kilograms per hectare, respectively).

If plant cover and development are inferior to that desired by the *second growing season*, fertilize again at rate given above.

Planting Maintenance.
Debris such as wood, styrofoam, algae and dislodged submerged plants accumulate in the high marsh and form a strand line. This material may smother and damage plantings particularly during the first two growing seasons. This litter should be removed in both the fall and the spring.

Canadian and Snow geese are fond of the tender roots and rhizomes of marsh plants and may destroy a planted area before establishment. Rope fences erected on the seaward edge of planted areas have been used successfully to exclude waterfowl during the first few growing seasons. The fences consist of wood, metal or plastic pickets strung with 1/8-inch nylon rope. The ropes are spaced at 6-inch (15 centimeters) intervals from the sediment surface to an elevation above MHW. (Dr. E. W. Garbisch, President, Environmental Concern Inc., personal communication, 1977.)

Labor Requirements.
Seeding may be accomplished with about 25 manhours of effort per acre. This figure includes harvest, storage, dispersal and tillage. Sprigs may be excavated, separated and planted for approximately 1 manhour per 100 plants. Labor per unit area is dependent upon plant spacing (18- and 24-inch spacing requires 200 and 100 manhours per acre, respectively.) Nursery seedlings will require about 5 manhours per 100 plants to prepare and plant. Labor requirements are 550 manhours per acre. Plugs will require about 10 manhours per 100 plants to prepare and plant. Labor requirements are 1,100 manhours per acre.

ENVIRONMENTAL FACTORS AFFECTING DESIGN

Several environmental factors are important in determining site suitability and choosing appropriate planting methods. Foremost of these are (1) tidal innundation, (2) salinity and (3) wave climate.

Tidal Innudation.
Submergence by the tides is probably the most important environmental factor affecting the distribution of intertidal plants. Smooth and California cordgrass are remarkably well adapted to withstand long periods of innundation. Most plants exchange gasses (breath) through small openings in their leaves known as stomata (from Greek meaning "mouth"). In California cordgrass the stomata are sunken, and the "lip-like" guard cells which surround the stomata are accompanied by subsidiary cells equipped with branched papilla (tiny finger-like projections). It is speculated that these papilla trap air bubbles and prevent the wetting of the stomatal apparatus during submergence (Kasapligil, 1976). Like many other members of the genus Spartina, smooth and California cordgrass contain large air spaces within their

shoots and roots. These air spaces (aerenchyma tissue) allow the plant to store its own supply of oxygen for respiration during submergence. (Johnson and York, 1915 and Purer, 1942.) Experiments have also demonstrated that oxygen is transported downward through these tissues to the plants subsurface roots and rhizomes (Teal and Kanwisher, 1965 and Wong, 1976). This adaptation may allow the lower portions of the plant to carry on respiration and exchange of gases via the emergent stems even when the plant is partially submerged. Because of this special adaptation, smooth and California cordgrass survive at lower elevations in the intertidal zone than any other emergent plant.

Woodhouse, Seneca and Broome concluded from their studies in North Carolina that smooth cordgrass usually grows between mean high water (MHW) and mean low water (MLW) in locations with narrow tidal ranges, and from MHW to mean sea level (term equivalent to 'mean tide level' on Pacific coast) in locations with broader tidal ranges. By applying what is known about the ability of cordgrass to conduct air from its emergent shoots to its submerged or subsurface parts, one can understand why tidal range is so important to the plant's survival at low intertidal elevations. As previously mentioned, smooth cordgrass shoots range from 2 to 8 feet (0.6 to 2.5 meters) in height. In an area which has only a 2-foot tidal range, the shoots of an average adult plant are exposed to the air even at high tide. In an area with a 5 foot tidal range, an average adult plant is totally submerged a portion of each day and must rely entirely upon its ability to store oxygen. Table 1 is a summary of four observations of smooth cordgrass survival in lower intertidal areas:

TABLE 1
SMOOTH CORDGRASS
TIDAL RANGE VS SURVIVAL

Location	Tidal Range (feet)	Lowest Survivors (feet MLW)
Snow's Cut, N.C. (Woodhouse, Seneca and Broome, 1972)	4.0	-0.5
Cold Springs Harbor, N.Y. (Johnson and York, 1915)	7.8	1.5
Romney Marsh, Mass. (Chapman, 1940)	9.2	3.0
Barnstable Marsh, Mass. (Redfield, 1972)	9.5	3.6

This data supports the previously discussed hypothesis of Woodhouse, Seneca and Broome on the elevational range of smooth cordgrass. However, in each of the study areas water level fluctuations were principally a

product of lunar tides. In areas with pronounced wind effect this relationship may not hold.

Table 2 summarizes some observations of California cordgrass survival in low intertidal areas of the Pacific Coast.

TABLE 2
CALIFORNIA CORDGRASS
TIDAL RANGE VS. SURVIVAL

LOCATION	TIDAL RANGE (feet)	LOWEST SURVIVORS (feet MLLW)
Bolinas Lagoon, Marin County (Rowntree, 1973)	4.5	2.1
Alameda Beach, near Bay Farm Island (Rowntree, 1973)	6.6	2.7
Palo Alto Marsh, near Palo Alto Yacht Harbor (Rowntree, 1973)	9.2	4.3

The elevational range of California cordgrass is more restricted than for smooth cordgrass. The lower range is approximately at mean tide level. The apparent difference in elevational distribution between smooth and California cordgrass may be a function of their respective tidal regimes rather than their inherent physical differences (California cordgrass is shorter).

On the Atlantic coast, though tidal range varies from one location to another, a specific coastal location will typically receive two high and two low tides of approximately equal magnitudes daily, thus giving a complete cycle every half-day. Tides along the Pacific coast also vary in range from one location to another, but unlike the Atlantic coast, the Pacific coast experiences a mixed semi-diurnal cycle. The full cycle of two different highs and two different lows requires one full day.

These tidal differences may affect plant survival in the lower intertidal zone. Rowntree (1973) has estimated that at Cold Springs Harbor on Long Island, New York (Johnson and York, 1915), cordgrass planted in March was subjected to an average period of daily submergence of about 17 hours (Table 1). Rowntree also estimated that the average period of daily submergence for plants at Alameda Beach in San Francisco Bay (Table 2) was slightly less (16 hours per day). However, the young plants at Cold Springs Harbor were only continuously submerged for approximately 8.5 hours per day. Young plants at Alameda Beach, because of the mixed semi-diurnal tides, were submerged continuously for up to 16.9 hours per day. These extended periods of submergence associated with Pacific tides may be the principal factor limiting the invasion of the lower intertidal zone by California cordgrass.

For all practical purposes, bank stabilization efforts on the Pacific coast can use mean tide level as the lower elevational extreme suitable for the propagation of California cordgrass. As a 'rule of thumb', smooth cordgrass can be planted throughout the intertidal zone in areas where tidal ranges are less than three feet. An exception to this is seeding. Because of the susceptibility of young plants, seeding should be conducted only in the upper 1/3 to 1/2 of the intertidal zone (Woodhouse, Seneca, and Broome, 1976 and Garbisch, 1976).

Salinity.

Substrate salinity will also influence the choice of planting method and the determination of site suitability. Many varieties of salt marsh plants reproduce, grow and survive as well or better when cultivated in freshwater environments. These marsh plants are referred to as "frugative halophytes", plants which tolerate but do not require saline environments. Other salt marsh plants require or prefer brackish waters. These plants are termed "true halophytes" or "salt obligates". Considerable research has been conducted on the salt requirements and/or tolerances of smooth cordgrass. In the field studies smooth cordgrass was observed tolerating salintiies between 2.5 parts per thousand (0/00) and 42.5 0/00 (Harshberger, 1911). Freshwater is an impetus to seed germination, and percent germination declines as salinity increases. However, after germination seedling growth is better in 5 to 10 0/00 salinity and is reduced in either freshwater or more salinine conditions, 40 0/00 (Mooring, Cooper and Seneca, 1971.) Considering the positive response of seedlings to brackish water, smooth cordgrass is probably best described as a "true halophyte".

Purer (1942) observed California cordgrass in saline environments from 22 0/00 to 39 0/00. Floyde (1976) found germination rates higher in 0 0/00 salinity than at 10 0/00, 20 0/00 and 30 0/00. Phleger (1971) subjected adult California cordgrass plants to nutrient solutions of from 0 to 125 percent sea water (0.0 - 41.25 0/00 salinity). Growth and survival was best in solutions of zero salinity, indicating that California cordgrass may be a frugative halophyte. However, the Phleger experiment lasted only eight weeks and should not be considered conclusive. The transplanted adult plants certainly began the experiment with an accumulation of salt in plant tissues. From this scant evidence it is impossible to postulate with any surety whether or not California cordgrass is a true halophyte like its Atlantic coast counterpart.

In general, neither plant is likely to be effective when used in saline environments higher than 40 0/00. Considering that salinity significantly inhibits seed germination, areas with salinities higher than 20 0/00 should be stabilized with sprigs, plugs, or seedlings.

Wave Climate.

Little definitive information is available concerning wave climates in which vegetative stabilization is likely to be effective. It is generally held that vegetation will successfully control erosion only in areas which are exposed to low and moderate wave stresses. However, this generalization does not allow thorough engineering consideration of this alternative on a project by project basis.

It is a complex task to describe wave environments in which vegetative stabilization has been effective. There is no single theoretical development for determining the actual growth of waves generated by winds in relatively shallow water (Coastal Engineering Research Center, 1973). In addition there are many physical and biological variables which must be acknowledged when comparing wave climate to plant survival. The tidal elevation coincident with a particular set of waves, as well as shore contours, will greatly influence the stress placed upon plantings. Also, the ability of a planted area to withstand wave stress will depend upon its growth stage, density, vigor and overall width.

To date, site suitability can be described only in qualitative terms. Table 3 provides several examples of vegetative stabilization field trials.

TABLE 3
VEGETATIVE STABILIZATION FIELD TRIALS

LOCATION	FETCH (Miles)	PLANT MATERIAL	EFFECTIVENESS
Alameda Creek,[1] San Francisco Bay, CA	0.1	Seeds Plugs	Success Success
Pine Knoll Shores[2] Bogue Sound, NC	1.5-4	Sprigs Seeds	Success Failure
Tred Avon River[3] Chesapeake Bay, MD	2-7	Seedlings	Success
Rich Neck, MD[3]	9	Seedlings	Success
Tilghman Point,[3] Chesapeake, Bay, MD	5-15	Seedlings	Failure
Cedar Island, NC[4] Lola Navy Facility	6-18	Sprigs	Success
Cedar Island, Radar[4] Tower, NC	6-18	Sprigs	Failure
Eastville, MD[3]	15-20	Seeds	Failure

[1]Knutson, 1976
[2]Woodhouse, Seneca and Broome, 1976
[3]Dr. E. W. Garbisch, President, Environmental Concern Inc., personal communication, 1977
[4]Woodhouse, Seneca and Broome, 1974

The only descriptive information of wave climate for the Table 3 sites is fetch (the distance the wind blows over the sea in generating waves). Fetch is one factor which influences wave generation; however, wind speed, wind duration and water depth are also critical determinants of wave characteristics in shallow water. From available data and field experience several general statements can be advanced.

Seeds are the least tolerant to wave attack and should be used for bank stabilization only in very sheltered environments, probably fetches of one mile or less. There have been no comparative studies of the wave tolerances of sprigs, seedlings and plugs. Nevertheless, it seems probable that single stemmed sprigs with little root matter are more susceptable to wave damage than either seedlings (3 to 5 months old) or plugs, both or which have mature aerial growth and well developed root systems. For this reason, sprigs have been arbitrarily assigned a fetch limitation of 5 miles in the next section on design guidelines. Vegetative stabilization appears to be consistantly effective in fetches up to about 10 miles. All of these limits are intended only as a general conservative guide. For instance, as may be noted in Table 3 (Cedar Island, NC), sprigs were used successfully in an area with a 6-18 mile fetch.

The other factors influencing wave climate; wind speed, duration and depth; must also be considered in determining site suitability. Each geographical region will have a characteristic wind climate. Local wind roses are useful in determining the direction from which the most severe winds occur. Planting sites which face these severe winds will be more difficult to stabilize.

Offshore depths substantially effect the height of waves that a particular storm will generate. Theoretically, a constant 30 mile per hour (48 kilometers per hour) wind blowing over water of a constant depth of 5 feet (1.5 meters) for a distance of 10 miles (16 kilometers) will generate waves less than 1.5 feet (0.5 meters) in height. (Coastal Engineering Research Center, 1973). The same conditions will produce waves nearly 3.5 feet (1.0 meters) high over water of a constant depth of 40 feet (12 meters). Therefore, areas with shallow offshore depths will be more easily stabilized.

A final consideration with respect to wave climate is the slope of the planting area itself. Waves will tend to dissipate their energy over a short distance when meeting an abrupt shoreline. On a gradual sloping shoreline, wave energy will tend to be dissipated over a longer distance. To dampen wave impact, planting areas should be sloped 1 vertical to 15 horizontal or flatter.

SUMMARY OF DESIGN GUIDELINES

The appropriate species and planting method may be determined in the following manner:

Step One.

Select the description from each of the following categories which best describes the site to be planted.

GEOGRAPHICAL AREA
- Atlantic coast
- Gulf coast
- Pacific coast (southern)

TIDAL ELEVATION
- Mean low water (MLW) to mean tide level (MTL)
- MTL to mean high water (MHW)
- MHW to estimate highest tide (EHT)

TIDAL RANGE
- 0.0 to 3.0 feet (1.0 meter)
- 3.0 feet or greater

SALINITY
- 0 to 20 parts per thousand
- 21 to 40 parts per thousand
- 41 to 60 parts per thousand

FETCH LENGTH
- 0.0 to 1.0 mile (1.6 kilometers)
- 1.1 to 5.0 miles (8.0 kilometers)
- 5.1 to 10.0 miles (16.0 kilometers)

Tidal elevations and tidal range can be estimated if detailed surveys are not available. To estimate tidal elevations, consult local tide tables and make site observations during low water and high water periods. Make these observations during calm periods when waves are low and there are no local storm fronts. Use reference stakes to delineate the tidal zone (MLW and MHW). Consider the midpoint between the high and low stakes to be MTL. Tidal range is the vertical difference between high and low water. Tide tables can be obtained from private distributors such as sporting goods stores, marinas and fishing concessions and from the U.S. Coast Guard and U.S. Geological Survey.

If specific information is not avialable, salinity can be estimated using the following general guidelines. Water begins to taste salty at about 3 parts per thousand. Seawater contains about 33 parts per thousand salt. In general, the waters of bays, sounds and estuaries will have salinities lower than seawater because of the influence of freshwater. Salinity will be less than 20 parts per thousand near bay mouths and inlet openings. Salinities greater than 40 parts per thousand are likely to be encountered only in areas where circulation is poor, evaporation rate is high, rainfall is low and temperatures are high. Additional information on local salinity regimes is often available from state departments of natural resources, academic institutions and the National Oceanic and Atmospheric Administration (NOAA).

Fetch length is the horizontal distance over which winds may blow across open water to create waves. Consider only the longest fetches.

Step Two.

Turn to the planting decision key (Figure 6 if site is located on the Atlantic or gulf coasts; Figure 7 if located on the Pacific

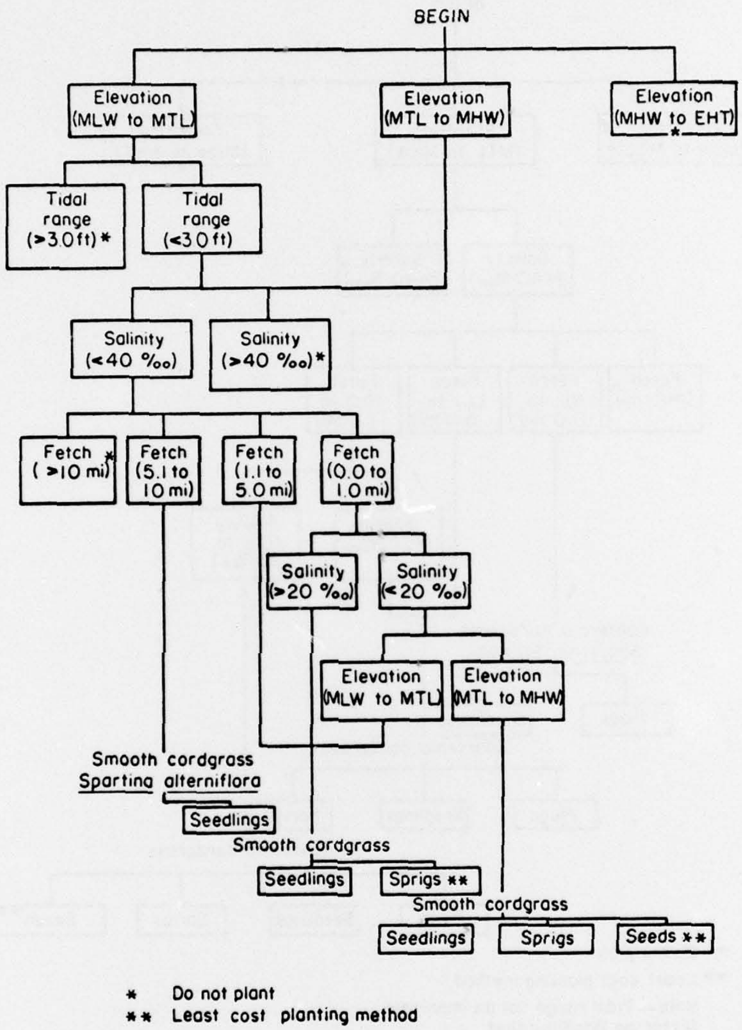

Figure 6. Planting decision key, Atlantic and gulf coasts.

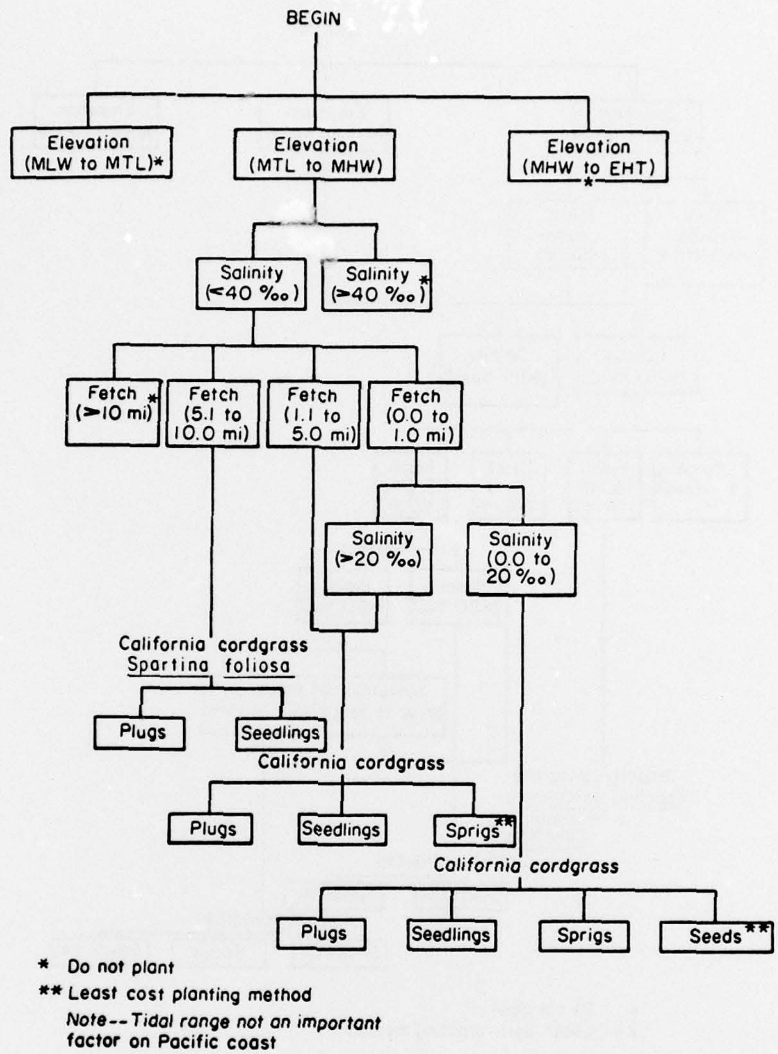

Figure 7. Planting decision key, Pacific coast.

coast). Using the appropriate planting decision key and the site description compiled in Step One, begin at the tip of the key and move downward following the appropriate path. The path will terminate in a block which either designates suitable plant species and planting methods or indicates the site is not appropriate for planting.

CONCLUSION

Vegetative stabilization should be a prime candidate in designs for erosion control in areas of low and moderate wave energies. Tidal fluctuations, salinity and wave climate are the principle considerations in determining site suitability and choosing appropriate planting methods.

More definative information is needed on the wave energies compatable with vegetative stabilization. However, since the cost of vegetative stabilization is usually less than $5.00 per linear foot, its use will be warrented even in cases where success is not certain.

ACKNOWLEDGEMENTS

This paper draws heavily upon marsh development research conducted by W. W. Woodhouse, Jr., E. D. Seneca and S. W. Broome of North Carolina State University at Raleigh; E. R. Garbisch, Jr., P. B. Woller and R. J. McCallum of Environmental Concern, Inc.; J. D. Dodd and J. W. Webb of Texas A&M University; and research performed by the author for the U.S Army Corps of Engineers, San Francisco District in conjunction with C. L. Newcombe, H. L. Mason and K. W. Floyd of the San Francisco Bay Marine Research Center, Inc. The illustration was prepared by Ms.Lynn Martin.

Publication of this paper has been approved by the Corps of Engineers, but all views, interpretations or conclusions are those of the author.

LITERATURE CITED

ANONYMOUS, Shore Protection Manual, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA,1973.

CHAPMAN, V. J., "Studies in Salt Marsh Ecology: VI-VII, Comparison with the Marshes on the East Coast of North America," Journal of Ecology 28:118-152, 1940.

CORREL, D., and CORREL, M., "Aquatic and Wetland Plants of Southwestern United States," EPA Publication, 1972.

FLOYD, K. W., "Feasibility of Littoral Plant Establishment for Shoreline Erosion Abatement in Greater San Francisco Bay Area," Fifth Quarterly Report, Contract No. DACW 72-75-C-0015 by the San Francisco Bay Marine Research Center, Inc., 1976.

GARBISCH, E. W. Jr., P. B. WOLLER, and R. J. MCCALLUM, "Salt Marsh Establishment and Development," TM-52, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Ft. Belvoir, VA., June 1975.

GARBISCH, E. W., Environmental Concern Booklet, St. Michaels, MD, 1976.

HARSHBERGER, J. W., "An Hydrometric Investigation of the Influence of Sea Water on the Distribution of Salt Marsh and Estuarine Plants," Proceedings of Amer. Phils. Soc., 50:457-496, 1911.

JOHNSON, D. S., and YORK, H. H. "The Relation of Plants to Tide Levels," Carnegie Institute Publications, Washington, D.C., 1915.

KASAPLIGIL, B., "A Synoptic Report on the Morphology and Ecological Anatomy of Spartina foliosa Trin," Enclosure 2, Appendix C of the San Francisco Bay and Estuary Dredge Disposal Study Appendix K, April 1976.

KNUTSON, P. L., "The Use of Dredged Material for the Development of Intertidal Marshlands," Proceedings of MTS/IEEE Ocean 75 Conference, San Diego, CA, pp 208-212, 1975.

KNUTSON, P. L., "Development of Intertidal Marshlands Upon Dredged Material in San Francisco Bay," Proceedings of Seventh World Dredging Conference, San Francisco, CA, U.S.A., July 10-12, pp 103-118, 1976.

MASON, H. L., A Flora of the Marshes of California, Univ. of California Press, Berkeley and Los Angeles, CA, 1969.

MOBBERLEY, D. G., "Taxonomy and Distribution of the Genus Spartina," Iowa State College, Journal of Science, 30:471-574, 1956.

MOORING, M. T., COOPER, A. W., and SENECA, E. D., "Seed Germination Response and Evidence for Height Ecophenes in Spartina alterniflora from North Carolina," American Journal of Botany, Vol. 58, No 1. pp. 48-55, Jan 1971.

MUNZ, P. A., A California Flora, Univ. California Press, Berkeley and Los Angeles, CA, 1968.

PHLEGER, C. F., "Effect of Salinity on Growth of a Salt Marsh Grass," Ecol. 52:908-911, 1971.

PURER, E. A., "Plant Ecology of the Coastal Salt Marshlands of San Diego County, California," Ecol. Monogr. 12:81-111, 1942.

REDFIELD, A. C., "Development of a New England Salt Marsh," Ecol. Monogr. 42(2):201-237, 1972.

ROWNTREE, R. A., "Morphological Change in a California Estuary: Sedimentation and Marsh Invasion at Bolinas Lagoon," Unpublished Ph.D. Dissertation, University of California, Berkeley, 1973.

TEAL, J. M., and KANWISHER, J. W., "Gas Transport in the Marsh Grass, Spartina alterniflora, "Woods Hole Oceanographic Institution, Woods Hole, Mass., 1965.

WOODHOUSE, W. W., Jr., SENECA, E. D., and BROOME, S. W., "Marsh Building with Dredge Spoil in North Carolina," North Carolina State University at Raleigh Agr. Exp. Sta. Bul. 445, pp. 28, 1972.

WOODHOUSE, W. W., Jr., SENECA, E. D., and BROOME, S. W., "Propagation of Spartina alterniflora for Substrate Stabilization and Salt Marsh Development," TM-46, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA, August 1974.

WOODHOUSE, W. W., Jr., SENECA, E. D., and BROOME, S. W., "Propagation and Use of Spartina alterniflora for Shoreline Erosion Abatement," TR-76-2, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA, August 1976.

WONG, G., "Oxygen Transport in Spartina foliosa Trin.," Inclosure 2 Appendix E of the San Francisco Bay and Estuary Dredge Disposal Study Appendix K, April 1976.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER R 78-2	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DESIGNING FOR BANK EROSION CONTROL WITH VEGETATION		5. TYPE OF REPORT & PERIOD COVERED Reprint
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Paul L. Knutson		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of the Army Coastal Engineering Research Center (CERRE-CE) Kingman Building, Fort Belvoir, Virginia 22060		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS D31530
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Army Coastal Engineering Research Center Kingman Building, Fort Belvoir, Virginia 22060		12. REPORT DATE February 1978
		13. NUMBER OF PAGES 18
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Bank stabilization
Erosion control
Marsh plants
Planting methods

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Marsh plants are effective in stabilizing eroding banks in sheltered coastal areas. Exceptional results have been achieved in a variety of intertidal environments at a fraction of the cost required for comparable structural protection. Techniques are available for the efficient propagation of several marsh plants for use in bank stabilization. This paper provides design criteria for (1) determining site suitability, (2) selecting plant materials and planting methods and (3) estimating labor requirements on a project by project basis.

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